



INFLUENCE OF ROAD GEOMETRY AND PERCENTAGE OF HEAVY VEHICLES ON CAPACITY AT MULTI-LANE HIGHWAYS IN EGYPT

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ABSTRACT

Multi-lane highways symbolize the plurality of the overall length of highway network in Egypt. The most serious factors affecting the capacity for any roadway are counted the road geometry and the percentage of heavy vehicles (HV). Subsequently, this research aims to discuss the relationship between the road geometric characteristics and HV, and capacity by statistical modeling. The modeling is divided into two models. First is the modeling for capacity on one direction of flow (C_{OD}) and second is the modeling for capacity on right lane (C_{RL}). In this study, the road geometric and traffic data are collected from straight section at 28 various sites that are located in desert highways. These sites are separated into 14 sections in divided four-lane roads, 7 sections in divided six-lane roads, and 7 sections in divided eight-lane roads. The results showed that the statistical modeling gives models with high R^2 (coefficient of determination) and low $\|\delta\|$ (percent error) values for estimating C_{OD} and C_{RL} . In addition, the most influential variables on C_{OD} in all sites are lane number (NL), median width (MW), and HV respectively, while the most influential variables on C_{RL} in all sites are MW and HV, respectively. These results are so important for road authorities in Egypt as they can determine capacity for different straight sections and improve the traffic performance of them in the future.

Key words: Capacity, Multi-Lane Highways, Right Lane, Heavy Vehicles and Regression Models.

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1. INTRODUCTION

The transportation system in Egypt is suffered from limited roadway infrastructure and the lack of operation and management experience. Among the most critical issues in highway planning and management is to explore the effectiveness of road geometric characteristics and HV in traffic composition on capacity at multi-lane rural highways. Rural multi-lane highways are an important type of uninterrupted flow facilities in which there is no obstruction to the movement of vehicles along the road. Those facilities perform the plurality of the highway system in Egypt. Subsequently, this paper aims to evaluate two types of capacity on multi-lane highways by statistical modeling. First is the right lane capacity (C_{RL}) and the second is the one direction capacity (C_{OD}).

Field data on multi-lane highways in Egypt are used in this investigation. The analysis considers 28 straight sections from three categories of highways. The first consists of divided four-lane highway (Suez-Ismailia Desert Highway), the second consists of divided six-lane highway (Alqantara-Ismailia Desert Highway), and the third consists of divided eight-lane highway (Alqantara-Port Said Desert Highway). Then, the paper includes two separate related models. The first uses the regression model to investigate the relationship between road geometric characteristics and HV percentage at one direction of flow as independent variables, and C_{OD} as dependent variables. The second uses the regression model to explore the previous relationship on right lane and comparing the results. The road geometric data are pavement width, lane width, median width, lateral clearance, and number of lanes in each direction. According to the objectives in this research, road authorities in Egypt can determine capacity for different multi-lane highway straight sections and improve the traffic performance of them in the future.

Sundry researches have been done to analyze the effect of road geometry and traffic properties on Capacity for multi-lane highways. The American Highway Capacity Manual [1] approved that the road capacity is highly linked to the free flow speed. Kerner [2] confirmed that the determination of capacity for any highway is one of the most important applications of any traffic theory. Some previous theories and empirical researches focused on the interrelationships among the influence of capacity, traffic features, and geometric elements on uninterrupted multi-lane highways [3–6].

Yang and Zhang [7] explored the effect of the lane number on the multi-lane road capacity utilizing site traffic flow information which was collected from Beijing. The results indicated that the lane average capacity is reduced by the increment of lane number on the studied highway sections. The minor reduction percent of mean lane capacity by increment of lane number is found to be about 6.7%.

Ben-Edigbe and Ferguson [8], studied the effect of highway state, pavement defects, on the capacity on two-lane roads depending on data collection from eight locations in Nigeria. The capacity computation procedure used the extracted required data from a basic graph indicating the traffic flow–density relationship. The capacities were computed in two adverse cases as without-distress and with-distress road segments.

Velmurugan et al. [9] examined the relation between the speed and the flow characteristics of different kinds of multi-lane roads in India. Consequently, the capacity of these highways was determined depending on conventional and microscopic emulation paradigms.

Semeida [10], studied the effect of road geometric properties and traffic characteristics on the right lane capacity at horizontal elements for multi-lane highway.

2. DATA COLLECTION

This research focuses on the rural multi-lane highways in Egypt. Therefore, the analysis of this paper uses 28 sites (sections) from three main multi-lane highways in Egypt. These roads include Suez-Ismailia Desert Highway (SID), Alqantara-Ismailia Desert Highway (AID), and Alqantara-Port Said Desert Highway (APD), Figure 1. These sites are divided into 14 sections in divided four-lane roads, 7 sections in divided six-lane roads, and 7 sections in divided eight-lane roads. Each section length is 100 m. The chosen sites are located on straight sections with level terrain to avoid the effect of the longitudinal gradient and to be far from the influence of horizontal curves. The collected data are divided into two types as road geometric characteristics and traffic properties data.



Figure 1 Multi-lane highways under study on Egyptian roads network

2.1. Road geometric data

These data are collected directly from field examination that included number of lanes in each direction, pavement width, lane width, median width, and lateral clearance. All the previous variables, their symbols, and statistical analysis are shown in Table 1.

2.2. Traffic properties data

Data was collected in 5 minutes time periods from 8:00 am till 5.00 pm (five hours at each site at least) in spring months (Mars, April and May) on Sunday, Monday, Tuesday and Wednesday in 2017. Data was carried out on the working days during the daylight hours in clear weather and on dry pavements. The data included traffic volume (Q), heavy vehicles percentage (HV), and density (K). In this study, the traffic data are collected twice. The first is for one direction of flow. The second is for right lane only. The video-recording method is used for traffic data collection. Video cameras strategically located at both ends of sections with passing lanes.

Table 1 Symbols of Independent variables and Statistical analysis

Variable	Variable symbol	Min.	Max.	Avg.	S.D.
Number of lanes in each direction in lanes	NL	2.00	4.00	2.75	0.84
Pavement width in meters	PW	9.25	16.61	13.00	2.24
Lane width in meters	LW	3.25	4.67	3.85	0.42
Median width in meters	MW	2.63	23.70	10.50	7.59
Lateral clearance in meters	LC	1.75	2.90	2.18	0.29
Percentage of heavy vehicles in direction %	HV	19.23	32.04	23.82	3.08
Percentage of heavy vehicles in lane %	HV _{RL}	20.09	54.73	36.50	8.93

2.2.1. Traffic volume data

During the data collection, manual traffic counting is carried out. The position of counting is nearly at midpoint of the straight section. The collected data involve the car class and the access time of car and are divided into 5-min periods. In every period, the number of cars at one direction of flow is transformed into PCU per hour per direction, and PCU per hour per lane for right lane.

2.2.2. Heavy vehicles percentage

From the recorded manual counting, the percentage of heavy vehicle types (HV), Table 1, is calculated at each site. Heavy vehicles contain semi-trucks, trucks and truck trailers that have at least one axle with dual wheels [11]. Finally, the effect of the different types of vehicles within a traffic stream is counted by converting the vehicles into passenger car units (PCU). GARBLT [11] specifies the PCU for all types of running vehicles on the Egyptian highways as shown in Table 2.

Table 2 PCU for all types of running vehicles on the Egyptian roads [11].

Types of vehicles	PCU
Motorcycles	0.5
Passenger cars, vans, mini-buses, minibuses, and jeeps (< 5 m)	1.0
Buses (> 8 m)	1.6
2 axle long (5-8 m)	1.9
2 axle 6 tire (5-8 m)	1.9
3 axle single (5-8 m)	1.9
4 axle single (> 8 m)	2.6
5 axle double (> 8 m)	2.6
6 axle double (> 8 m)	2.6
6 axle multi (> 8 m)	2.6

2.2.3. Density data

For each direction, the density is calculated in (veh/km/dir) for one direction of flow and (veh/km/lane) for right lane. It is measured simply in the field, by counting the vehicles number throughout the length of each straight section. Finally, the density is considered by converting the vehicles number per section length into PCU/km.

Influence of Road Geometry and Percentage of Heavy Vehicles on Capacity at Multi-Lane Highways In Egypt

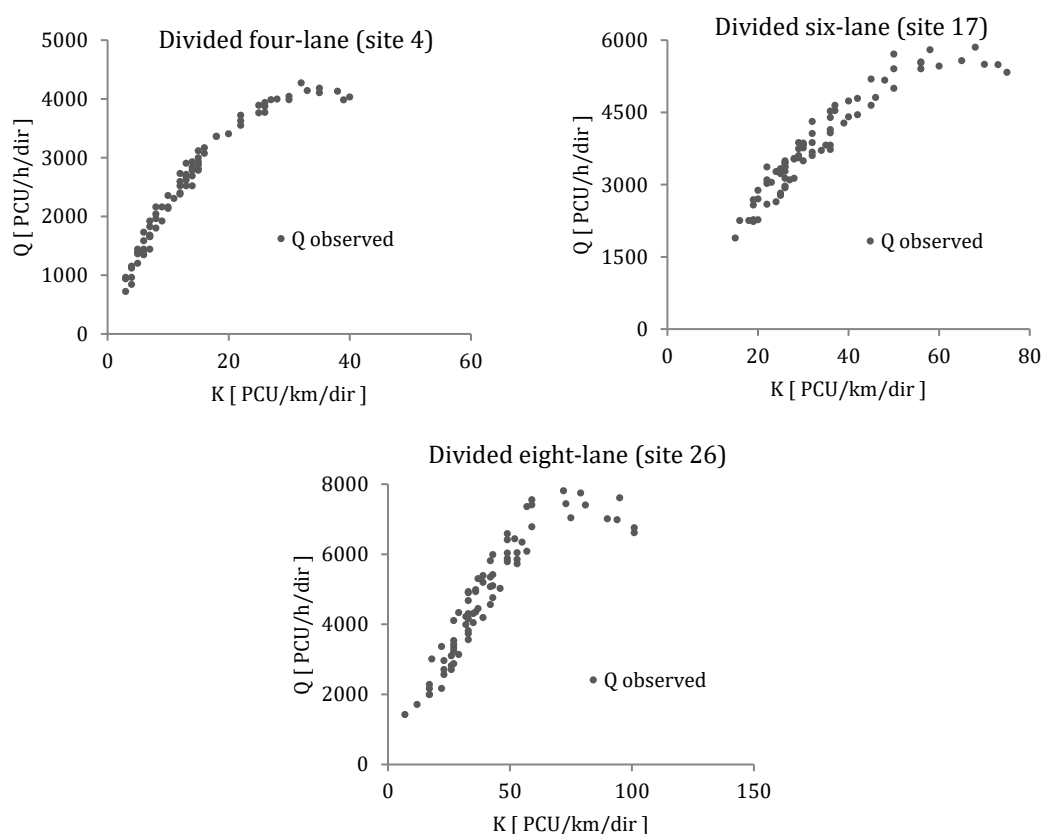


Figure 2 Flow rate and density relationship on one direction of flow for sites 4, 17, 26

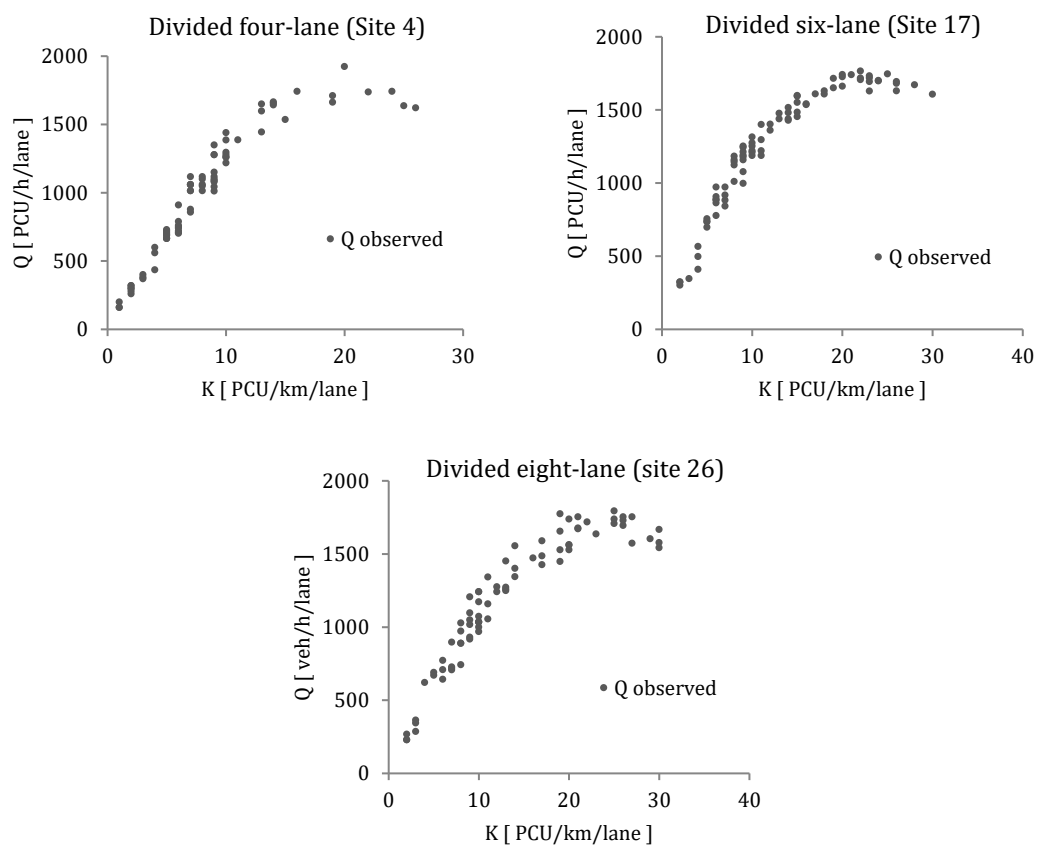


Figure 3 Flow rate and density relationship on right lane for sites 4, 17, 26

The results of the two types of density are plotted versus flow rate as shown in Figures 2 and 3, which declare the relationship between flow rate and density at three sections. The first section represents the divided four-lane, the second represents the divided six-lane, and the third represents the divided eight-lane. This relationship shows that the traffic stream represents clearly one condition of flow (steady state) at the three sections indicating that the case of bottleneck is formed on these sections. Therefore, these highways carry traffic volumes close to the capacity value. Therefore, the capacity can be reached from reliable curve fitting of the traffic data at each site [12].

3. METHODOLOGY

3.1. Capacity determination methodology

A direct-empirical procedure, [12] depending on the observed volumes and densities is employed to determine the capacity. In this method, the capacity can be measured either directly from the traffic data, if the road section forms a bottleneck, or estimated by extrapolating the steady flow observations. Investigation of Figures 2 and 3 show that the capacity conditions are reached because these sites carry high traffic volumes close to the capacity value. However, the critical density can be derived directly by reliable curve fitting of the traffic data at each site.

The flow-density relationship has been described by van Arem et al. [13] and Minderhoud et al. [14] as having a quadratic form, Equation 1.

$$Q = \beta_0 + \beta_1 \cdot D + \beta_2 \cdot D^2 \quad (1)$$

To achieve the bell shape of this relation, the sign of β_2 should be negative or zero and positive for β_1 . It emphasized that the capacity of highway can be determined when the flow-density relationship takes the bell shape in which the critical density is attained at the crest point of the curve, where the capacity value occurs at the maximum value of flow. In the present study, the traffic capacity is determined by the method of square function, and the crest point of the curve produces the capacity.

3.2. Capacity modeling procedure

The collected data are used to investigate the relationships between capacity as dependent variable and road geometric and HV percentage as independent variables. Simple regression is used to check the correlation coefficient (r) between each dependent variable and each of the independent variables. The independent variables that have relatively high r values (>0.5) are introduced into the multiple linear regression models. The form of multiple linear regression models is shown in Equation 2.

$$Y = \beta_0 + \sum_{i=1}^n \beta_i x_i \quad (2)$$

where Y is the capacity, X_i the explanatory variables from 1 to n , β_0 is the regression constant, and β_i is the regression coefficient.

Then, stepwise regression analysis is used to select the most statistically significant independent variables with dependent variable in one model. Stepwise regression starts with no model terms. At each step, it adds the most statistically significant term (the one with lowest P -value) until the addition of the next variable makes no significant difference. An important assumption behind the method is that some input variables in a multiple regression do not have an important explanatory effect on the response. Stepwise regression keeps only the statistically significant terms in the model. Finally, the R^2 (coefficient of determination) and (percent error)

$\|\delta\|$ values are calculated for each model. Several precautions are taken into consideration to ensure integrity of the model as follows [15-16]:

- The signs of the multiple linear regression coefficients should agree with the signs of the simple linear regression of the individual independent variables and agree with intuitive engineering judgment.
- There should be no multicollinearity among the final selected independent variables.
- The model with the smallest number of independent variables, minimum $\|\delta\|$, and highest R^2 value is selected.

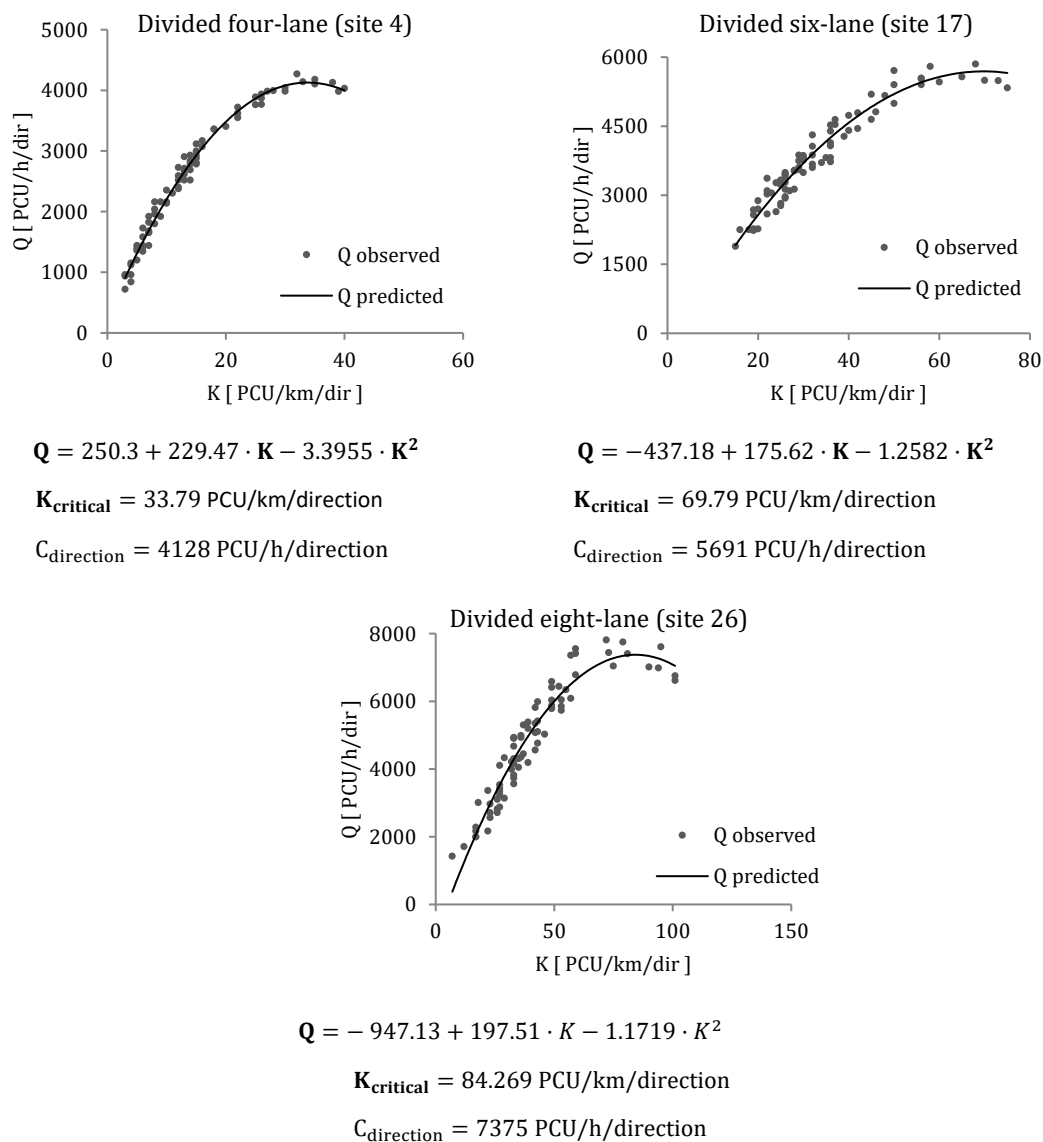


Figure 4 Observed data, fitting curves, and the derived capacity at one direction for the sites 4, 17, 26

4. Results and Discussion

4.1. Capacity determination results

Due to the lot of calculations needed for capacity evaluation on one direction of flow and right lane on the straight sections, the analysis is conducted for one section of each road type: section 4 presents divided four-lane, section 17 presents divided six-lane and section 26 presents divided eight-lane.

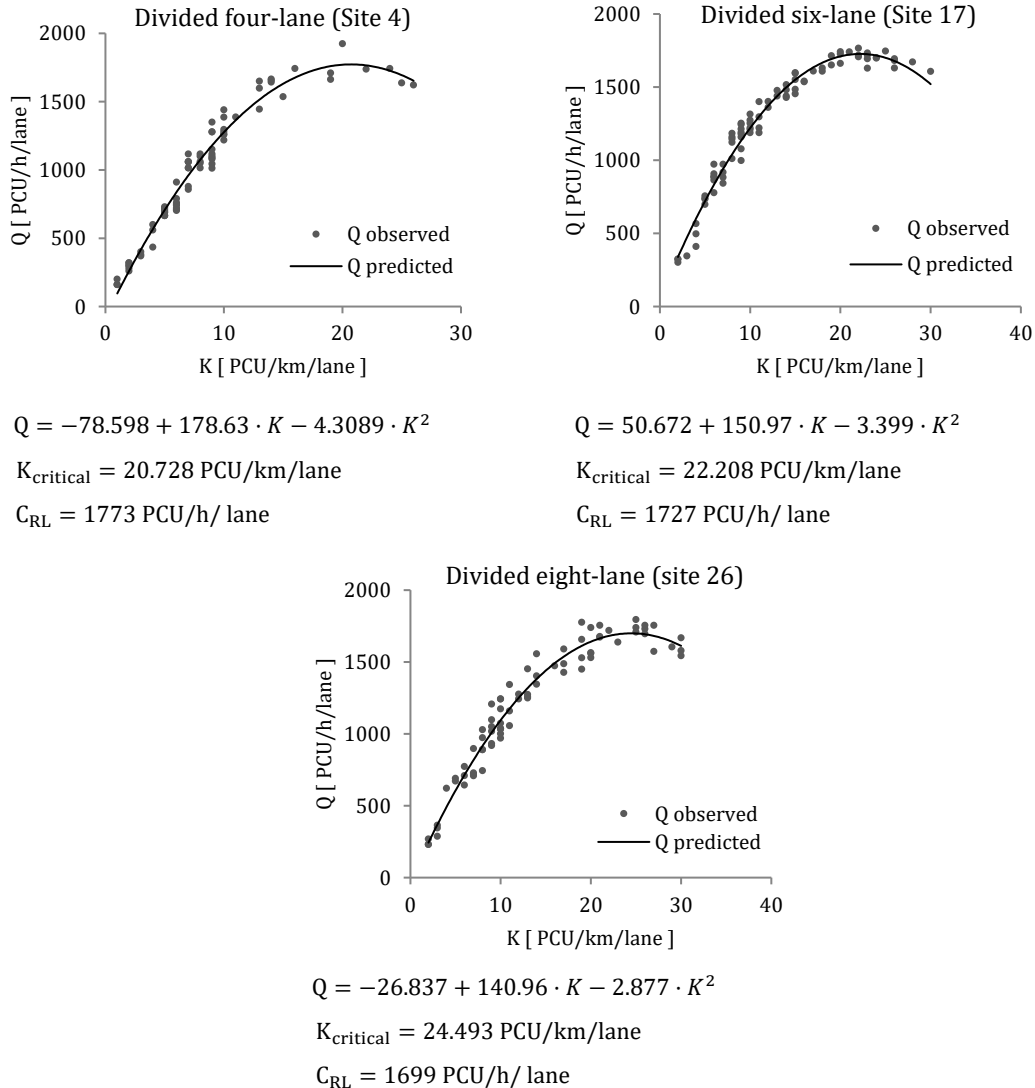


Figure 5 Observed data, fitting curves, and the derived capacity at right lane for the sites 4, 17, 26

On using the traffic data, the vehicle counts for each 5-min interval for each vehicle type are converted to 5-min flow rates (Q) in PCU/h. The densities for each 5-min interval (K) are determined in PCU/km. Consequently, the square equations among flow and density are standardized, and the equation coefficients for both cases are computed by Equations from 2 to 7.

The coefficients of the model must have the suitable signs that give the bell shape function; also their values must be extremely greater than zero at the 95% level of confidence. Consequently, the critical density and capacity value for the three sections are given as shown in Figures 4 and 5.

$$Q_{sec.4} = 250.3 + 229.47 \cdot K - 3.3955 \cdot K^2$$

(Whereas, $R^2 = 0.9861$) (2)

$$Q_{sec.17} = -437.18 + 175.62 \cdot K - 1.2582 \cdot K^2$$

(Whereas, $R^2 = 0.9456$) (3)

$$Q_{sec.26} = -947.13 + 197.51 \cdot K - 1.1719 \cdot K^2$$

(Whereas, $R^2 = 0.9255$) (4)

$$Q_{sec.4}(RL) = -78.598 + 178.63 \cdot K - 4.3089 \cdot K^2$$

(Whereas, $R^2 = 0.9697$) (5)

$$Q_{sec.17}(RL) = 50.672 + 150.97 \cdot K - 3.399 \cdot K^2$$

(Whereas, $R^2 = 0.9739$) (6)

$$Q_{sec.26}(RL) = -26.837 + 140.96 \cdot K - 2.877 \cdot K^2$$

(Whereas, $R^2 = 0.9617$) (7)

The observed data, the suitable curves, and the derived capacity for the three sections are shown in Figures 4 and 5. The terminated models for all conditions have the expected signs and the determined coefficients (R^2) must be better than 0.8. The capacity values for all the 28 straight sections are presented in Table 3.

4.2. Capacity modeling results

First, each independent variable is modeled with capacity by Simple regression. The analysis considers linear mathematical forms of the independent variables. These results are shown in Table 4. Then, these variables are introduced into the multiple linear regression models. Consequently, stepwise regression analysis is used to select the most statistically significant independent variables with capacity in one model.

The modeling is divided into two models. The first uses the 28 sections to investigate the C_{OD} model. The second uses the same 28 sections to investigate the C_{RL} model.

Table 3 The values of one direction capacity and right lane capacity for all sites.

Site No.	C_{OD} (PCU/h/dir)	C_{RL} (PCU/h/lane)	Site No.	C_{OD} (PCU/h/dir)	C_{RL} (PCU/h/lane)
1 (2-lane)	3678	1803	15 (3-lane)	6630	1753
2 (2-lane)	3715	1860	16 (3-lane)	6153	1756
3 (2-lane)	3901	1913	17 (3-lane)	5691	1727
4 (2-lane)	4128	1773	18 (3-lane)	6740	1800
5 (2-lane)	3688	1848	19 (3-lane)	5313	1694
6 (2-lane)	3734	1919	20 (3-lane)	5603	1801
7 (2-lane)	4111	2045	21 (3-lane)	6791	1790
8 (2-lane)	4081	1800	22 (4-lane)	10021	1674
9 (2-lane)	3955	1947	23 (4-lane)	9022	1605
10 (2-lane)	3865	1922	24 (4-lane)	8112	1626
11 (2-lane)	3412	1916	25 (4-lane)	10131	1691
12 (2-lane)	4082	1788	26 (4-lane)	7375	1699
13 (2-lane)	4033	1793	27 (4-lane)	8597	1686
14 (2-lane)	3862	1795	28 (4-lane)	7499	1547

Table 4 Correlations between capacity and each of independent variables.

Variable	R^2	P -value	R^2	P -value
	One direction capacity models		Right lane capacity models	
NL	0.914	0.000	0.672	0.000
LW	0.575	0.000	0.846	0.000
PW	0.799	0.000	0.376	0.000
MW	0.437	0.000	0.511	0.000
LC	0.186	0.022	0.507	0.000
HV	0.029	0.386	0.941	0.000

4.2.1. C_{OD} model.

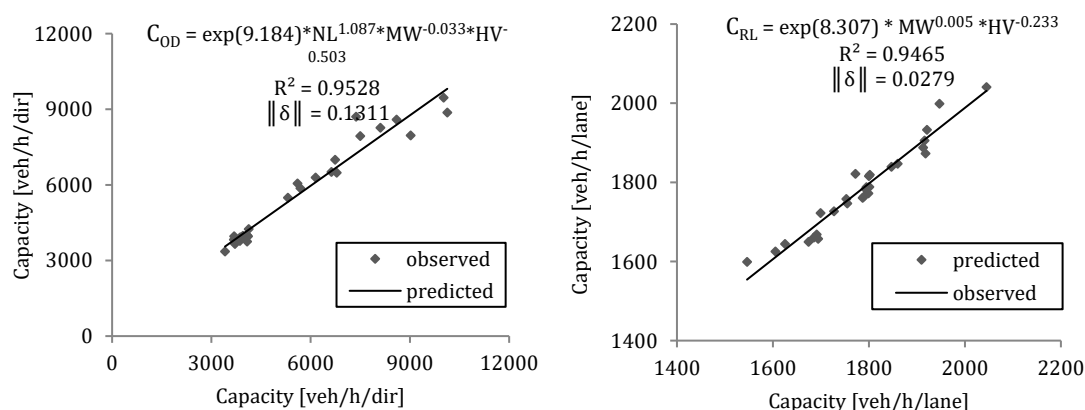
There are six models that are statistically significant with C_{OD} after stepwise regression using SSPS Package. All of the variables are significant at the 5% significance level for these models (P -value is <0.05). Finally, many models are excluded due to poor significance with C_{OD} . Thus, the best model is as follows in Equation 8 and shown in Figure 6.

$$C_{OD} = e^{9.184} * NL^{1.087} * MW^{-0.033} * HV^{-0.503}$$

(Whereas, $R^2 = 0.9528$, $\|\delta\| = 0.1311$) (8)

Investigating the best models for the one direction capacity, it is found that:

- The positive sign of the coefficient for the power of NL means that the most NL increases the C_{OD} of this section. The previous results are consistent with logic.
- The negative sign of the coefficient for the power of MW means that the C_{OD} increases with the decrease in MW.
- The negative sign of the coefficient for the power of HV means that the C_{OD} decreases with the increase in HV. The sections with higher HV are more congestive and the drivers of passenger cars are annoyed with HV which force them to decrease their speed.

**Figure 6** Observed and predicted capacity for the best regression models

4.2.2. C_{RL} model.

There are six models that are statistically significant with C_{RL} after stepwise regression using SSPS Package. All of the variables are significant at the 5% significance level for these models (P -value is <0.05). Finally, many models are excluded due to poor significance with C_{RL} . Thus, the best model is as follows in Equation 9 and shown in Figure 6.

$$C_{RL} = e^{8.307} * MW^{0.005} * HV^{-0.233}$$

$$(\text{Whereas, } R^2 = 0.9465, \|\delta\| = 0.0279) \quad (9)$$

Investigating the best models for the right lane capacity, it is found that:

- The positive sign of the coefficient for the power of MW means that the C_{RL} increases with the increase in MW.
- The negative sign of the coefficient for the power of HV means that the C_{RL} decreases with the increase in HV. The sections with higher HV are more congestive and the drivers of passenger cars are annoyed with HV which force them to decrease their speed.

5. CONCLUSION

The present study examines the effectiveness of road geometry and heavy vehicles percentages on capacity at straight section for the Egyptian major highways. Two types of capacity are modelled; capacity at one direction of flow (C_{OD}) and capacity at right lane (C_{RL}). The most important findings are given here below:

One direction Capacity

- 1) For all sections, the best C_{OD} regression model gives R^2 and $\|\delta\|$ equal to 0.9528 and 0.1311 for overall data set.
- 2) The most influential variables on C_{OD} of all sections are NL, followed by MW then HV.
- 3) The increase in NL by one lane leads to an increase in C_{OD} by nearly 2400 veh/hr/dir.
- 4) For divided four-lane, the increase in MW by 1 m leads to a decrease in C_{OD} by nearly 20 veh/hr/ln. Also, the increase in HV by 1% leads to a decrease in C_{OD} by nearly 32 veh/hr/ln.
- 5) For divided six-lane, the increase in MW by 1 m leads to a decrease in C_{OD} by nearly 113 veh/hr/ln. Also, the increase in HV by 1% leads to a decrease in C_{OD} by nearly 43 veh/hr/ln.
- 6) For divided eight-lane, the increase in MW by 1 m leads to a decrease in C_{OD} by nearly 235 veh/hr/ln. Also, the increase in HV by 1% leads to a decrease in C_{OD} by nearly 79 veh/hr/ln.

Capacity on right lane

- 7) For all sections, the best C_{RL} regression model gives R^2 and $\|\delta\|$ equal to 0.9465 and 0.0279 for overall data set.
- 8) The most influential variables on C_{RL} of all sections are HV, followed by MW.
- 9) For divided four-lane, the increase in HV by 5% leads to a decrease in C_{RL} by nearly 80 veh/hr/ln. Also, the increase in MW by 2 m leads to an increase in C_{RL} by nearly 30 veh/hr/ln.
- 10) For divided six-lane, the increase in HV by 5% leads to a decrease in C_{RL} by nearly 41 veh/hr/ln. Also, the increase in MW by 2 m leads to an increase in C_{RL} by nearly 51 veh/hr/ln.
- 11) For divided eight-lane, the increase in HV by 5% leads to a decrease in C_{RL} by nearly 53 veh/hr/ln. Also, the increase in MW by 2 m leads to an increase in C_{RL} by nearly 103 veh/hr/ln.

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